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Design and Construction
of a
Homopolar Dynamo

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DESIGN AND CONSTRUCTION

OF A

HOMOPOLAR DYNAMO

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED DESIGN AND CONSTRUCTION OF A HOMOPOLAR DYNAMO

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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DESIGN AND CONSTRUCTION OF A HOMOPOLAR DYNAMO.

Introduction :-

The earliest machine which has any right to be called a dynamo, namely, the rotating copper disc of Faraday, was of the homopolar class. About 1878, Dr. Werner Siemens designed a homopolar machine in which there were two cylinders of copper, each of which rotated round one pole of a "U" shaped electromagnet. A second electromagnet was placed between the rotating cylinders, with protruding pole-pieces of arching form which embraced the cylinders above and below. Each cylinder, therefore, rotated between an internal and an external pole of opposite polarity, and consequently cut the lines of force continually by sliding on the inner pole. The currents from this machine were very great, but the pressure was only a few volts. To keep down the resistance, many collecting brushes pressed on

the cylinders at each end.

Much attention has been paid in recent years to machines of this class. Mr. Willoughby Smith showed that if an iron rotor were used instead of a copper rotor, a much more powerful effect was obtained. Professor George Forbes constructed a machine with an iron cylinder, rotating within an entirely self-contained field magnet. A rubbing contact - for which Professor Forbes at one time used carbon brushes, and at another time springy strips of metal foil - was maintained at the two extremities of the periphery. One of these machines, in which the armature was a cylinder of iron nine inches in diameter and eight inches long, was designed to give a current of ten thousand amperes at one volt pressure when running at one thousand revolutions a minute. Mr. C. E. L. Brown designed a homopolar machine with a cylinder of copper rotating between the lips of an iron-clad electromagnet of cast-iron. The current was collected at the ends of

the periphery, as in Professor Forbe's machine, by means of metal brushes. This machine at twelve hundred revolutions per minute developed a pressure of ten volts and showed hardly any perceptible drop in voltage when a current of three thousand amperes was taken from it. This was the first really practical homopolar machine.

The machine which is dealt with in this thesis was patterned in a general way after Mr. Brown's design. Cast steel was selected as the material for the armature and the field because of its great mechanical strength and high permeability, which qualities would permit of high peripheral velocity of the armature and a minimum weight of material for the magnetic circuit, respectively. The collection of current was designed to be by means of twenty graphitic carbon brushes bearing radially upon the periphery of the cylinder, half of the brushes being placed at each end of the armature.

Electrical Calculations :-

For a homopolar dynamo of 10 KW to deliver 1000 amperes at 10 volts.

ARMATURE :- The electromotive force generated by a conductor moving thru a magnetic field is expressed by the formula $E = vlB \div 10^8$ where v is the linear velocity of the moving conductor in inches per second, l is length in inches at right angles to the direction of motion, and B is the density of the field in lines per square inch.

Allowing two volts for IR drop in the machine, the total generated pressure must be twelve volts in order to have a terminal pressure of ten volts at full load. Then, taking $E = 12$ and $B = 100,000$, we may write

$$12 = \frac{vl \times 100,000}{10^8}$$

or

$$vl = 12000$$

In order to secure a minimum weight for the given output of the machine, a peripheral speed of 12000 feet per minute was decided upon, this speed to be attained by an armature of

fairly small diameter and a high R.P.M. The value of 12000 feet per minute for peripheral velocity is common in turbine practice.

Then $\qquad v = \dfrac{12000 \times 12}{60} = 240\ ^{in}/sec.$

and $\qquad l = \dfrac{12000}{240} = 5''.$

A mean diameter of $19\frac{1}{2}''$ was finally decided upon. Then we have

$$R.P.M. = 12000 \div \frac{19.5\ \pi}{12} = 2350$$

The thickness of the cylindrical shell was taken as .45".

<u>FIELD:-</u> The accompanying assembly drawing will give an idea of the form of field magnets decided upon.

Magnetic path per magnet = 45.7 cm.

From a magnetization curve for cast steel, we find that for a density of 100,000 lines per square inch or 15,000 lines per square centimeter -

Ampere turns per cm. = 20.

Then amp. turns per magnet = 20 x 45.7 = 914.

An air gap of .05" was left inside and outside of the cylindrical shell of the armature, thus making a total air-gap of .10". Then the ampere turns required to force 100,000

lines per square inch across this gap =

$$.3133 \times 100,000 \times .10 = 3133.$$

Then total ampere turns per magnet =

$$914 + 3133 = 4000 \text{ (approx.)}$$

This magnetizing power can be obtained by 1000 turns of #15 wire carrying a current of 4 amperes. The placing of this field winding is indicated on the drawing. The total length of wire per magnet was figured at 5000 feet. Then, since #15 wire has a resistance per foot of .00323 ohms.

Resistance per coil = $5000 \times .00323 = 16.0^{\omega}$.
and the resistance of the two coils in series would be 2×16 or 32^{ω}.

The pressure required to force the required current of 4 amperes thru the field windings would then be 32×4 or 128 volts.

Owing to the enclosed position of the field windings, there is likelihood of a considerable temperature rise there and for this reason it was thought best to specify an insulation which would stand a high temperature without deterioration. Such an insulation is

"Deltabeston", made by the D. & W. Fuse Co. of Providence, R.I. This insulation will stand 350° F without harm.

#15 wire in concealed work can carry 8 amperes according to Underwriters' Rules. Hence a current much above 4 amperes can be sent thru the field windings if so desired.

BRUSHES:- According to the only data available, the resistance of carbon brushes is 2500 microhms per cubic inch.

The brushes were designed to work in brass tubes passing radially thru the outer lips of the field magnets and insulated from them. The active length of two brushes, one positive and one negative, was taken as 6".

The current per brush was 100 amperes, there being 10 brushes of each polarity carrying 1000 amperes in all. The permissable brush drop was taken as 1 volt. Then $R = \frac{1}{100} = .01^{\omega}$ and the resistance per inch length $= \frac{.01}{6} = .00166^{\omega}$. The cross-section required $= \frac{.00250}{.00166} = 1.5$ sq. in., giving a brush $1\frac{3}{8}$" in diameter.

Connection was made to each brush from a heavy cast iron terminal ring by an insulated flexible copper conductor soldered into a brass ring encircling the brush and clamped to it by means of three machine screws. The conductor cross-section was equivalent to that of a #3 B. and S. wire.

BRUSH SPRINGS:- Provision was made to press the brushes down on the cylinder by means of brass springs bearing upon the brass ring encircling the brushes. The end of the spring bearing upon the ring was forked in each case, so as to exert pressure at both ends of a diameter of the ring and so press the brush radially on the cylinder. The other end of each spring was securely screwed to the cast-iron terminal ring.

Assuming 1.5# per square inch as a reasonable brush pressure, the brushes should then each exert a pressure of 1.5 x 1.5 or 2.25# on the cylinder. Springs made out of #16

B. and S. (.05") sheet brass should easily furnish this pressure. The pressure of the spring on the brush can be adjusted by moving the brass ring on the brush. Wear of the brush can be taken up in the same manner.

<u>TERMINAL RING:-</u> Taking current from the terminal ring at the bottom, the maximum current thru each side of the ring will be 500 amperes. The active length of each half of the ring is 3 feet. Allowing .1 volt IR drop over this length, $R = \frac{.1}{500} = .0002^{\omega}$ and the resistance per foot $= .000067^{\omega}$. The resistance per circular-mil-foot of copper is 10.8^{ω} and a like value for cast iron is 12×10.8 or 130^{ω} (approx.) Then the resistance per square-mil-foot $= .7854 \times 130 = 102^{\omega}$. The cross-section required for the ring is then given by $\frac{102}{.000067} = 1,500,000$ sq. mils. $= 1.5$ square inches. Taking the ring as 3" wide, the thickness will be $\frac{1.5}{3}$ or .5".

Cast iron was selected for the material of these rings because

it was cheap and made a ring which not only served as a conductor but as a convenient place of attachment for the brush springs. These rings were secured to the field rings by means of cap screws insulated from the terminal rings by fiber bushings and washers.

BRUSH CONTACT DROP:- As no data for brush contact resistance between carbon brushes and cast steel at the high peripheral speed to be used in this machine could be found, the brush contact drop was necessarily left an unknown quantity to be determined from the operation of the machine.

In this matter of current collection and contact drop lies the principal difficulty to be encountered in this as in former homopolar machines, and the operating characteristics of the machine in these regards cannot be predetermined.

Mechanical Calculations:-

CENTRIFUGAL STRESS IN CYLINDER:-

To get the centrifugal force on each pound of metal in the shell of the cylinder:- The centrifugal force in pounds

$$F = \frac{W v^2}{32.16 R}$$

where $\underline{W}$ is weight in pounds, $\underline{v}$ is linear velocity of the center of gravity of a unit section of the cylindrical shell, and $\underline{R}$ is radius in feet. Then

$$F = \frac{\left(\frac{12000}{60}\right)^2}{32.16 \times \frac{19.5}{2 \times 12}} = 1530 \text{ lbs.}$$

To get the centrifugal tension in the shell of the cylinder:- This tension

$$P = \tfrac{1}{2} m \bar{r} \omega^2$$

where $\underline{m}$ is the mass of one half of the shell, $\bar{r}$ is the distance from the axis to the mass center of one half of the shell and $\underline{\omega}$ is the angular velocity. The weight of one half the shell was $88.7^{\#}$ and its mass $\frac{88.7}{32.16}$ or 2.76 "gee" pounds. $\bar{r}$ was calculated to be equal to $\frac{\text{diameter}}{\pi}$, in this case 6.2". Then $P = \frac{1}{2} \times 2.76 \times \frac{6.2}{12} \times \left(\frac{2350}{60} \times 2\pi\right)^2$

$$= 43,200^{\#}$$

Cross-section of shell = 11.5 × .45 = 5.17 □".

Then the tensile stress per sq-inch in the shell $= \frac{43,200}{5.17} = 8,350$#
and the factor of safety is approximately eight, a figure which should insure the safety of the cylinder.

<u>SHAFT AND BEARINGS</u>:- The peripheral velocity of the shaft $= 2350 \times \frac{1.5\pi}{12}$ or 923 feet per minute. The weight of the armature and shaft approximates 250 pounds. Then the pressure on each of two bearings is 125 pounds.

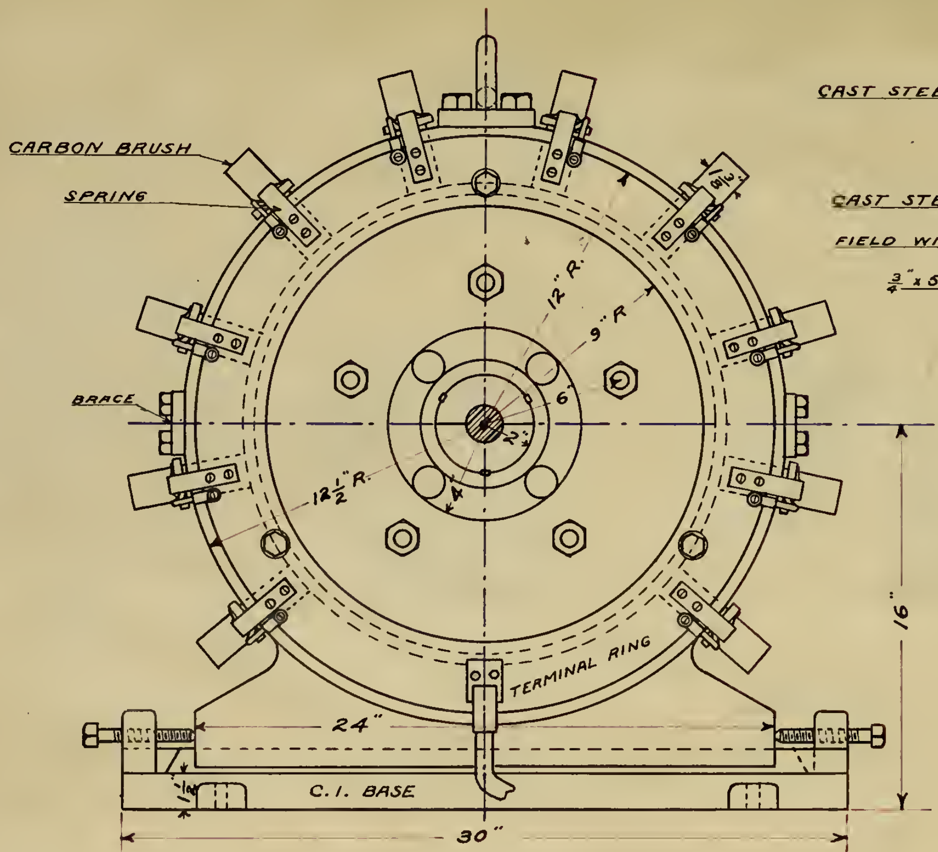
Stock bearing brasses were obtained from the Kerr Turbine Company of Wellsville, N.Y. These brasses were split, and were made of a hard bearing bronze warranted to stand 225° F. without seizing. These brasses were 2.5" long and were bored for a 1.5" shaft. The projected area of the bearing was then $2\frac{1}{2} \times 1\frac{1}{2}$ or $3\frac{3}{4}$ square inches and the bearing pressure per square inch of projected area was accordingly $\frac{125}{3.75}$ or 33.3 pounds. This is a fairly low value and should insure good wearing qualities even at such a high shaft velocity.

The brasses were arranged for ring oiling and were carefully chamfered inside in such a manner that the oil was dragged into the bearing and the shaft was practically supported on a film of oil. Such lubrication as this permits of the use of bearing pressures much higher than those occuring in this machine.

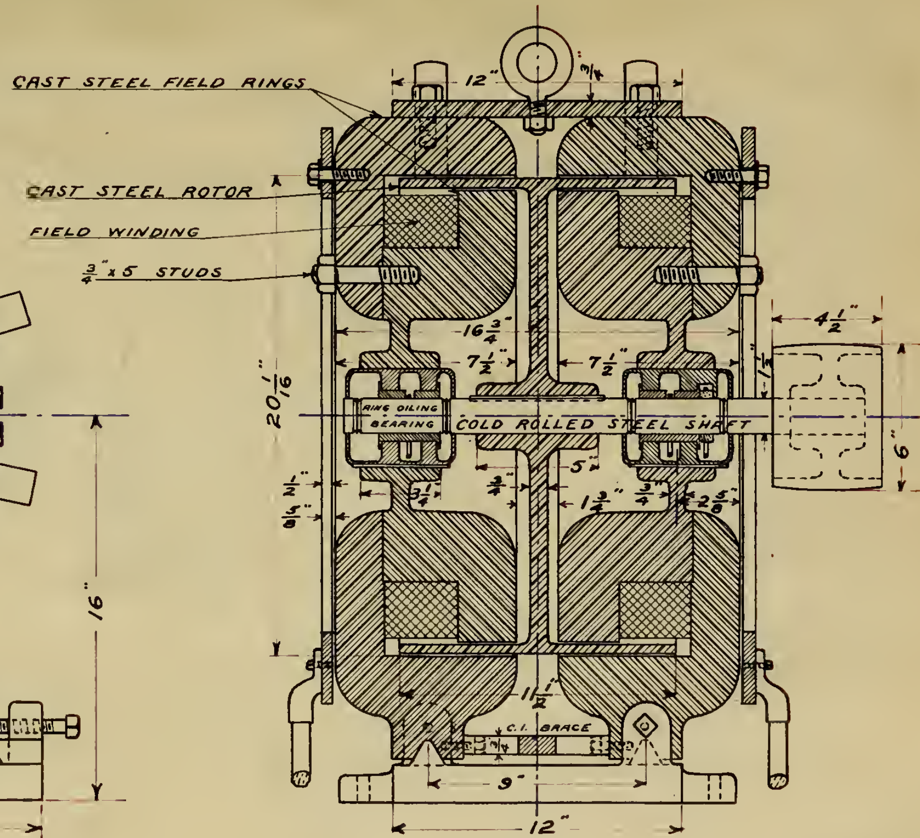
Split boxes of cylindrical form were constructed for these brasses and were arranged to be keyed into a cylindrical hole thru the inner field rings. The details of construction of these bearings can be seen from the accompanying drawings. The boxes were made to fit loosely in the field rings so that a certain amount of adjustment of the bearings was possible by means of the keys.

Weight of Machine :- The weight of the machine complete, with base, will closely approximate 2050 pounds.

Ernest Hungerford Johnston
Stanley Prince Farwell.
Arthur Evans Ray



ELEVATION



SECTION

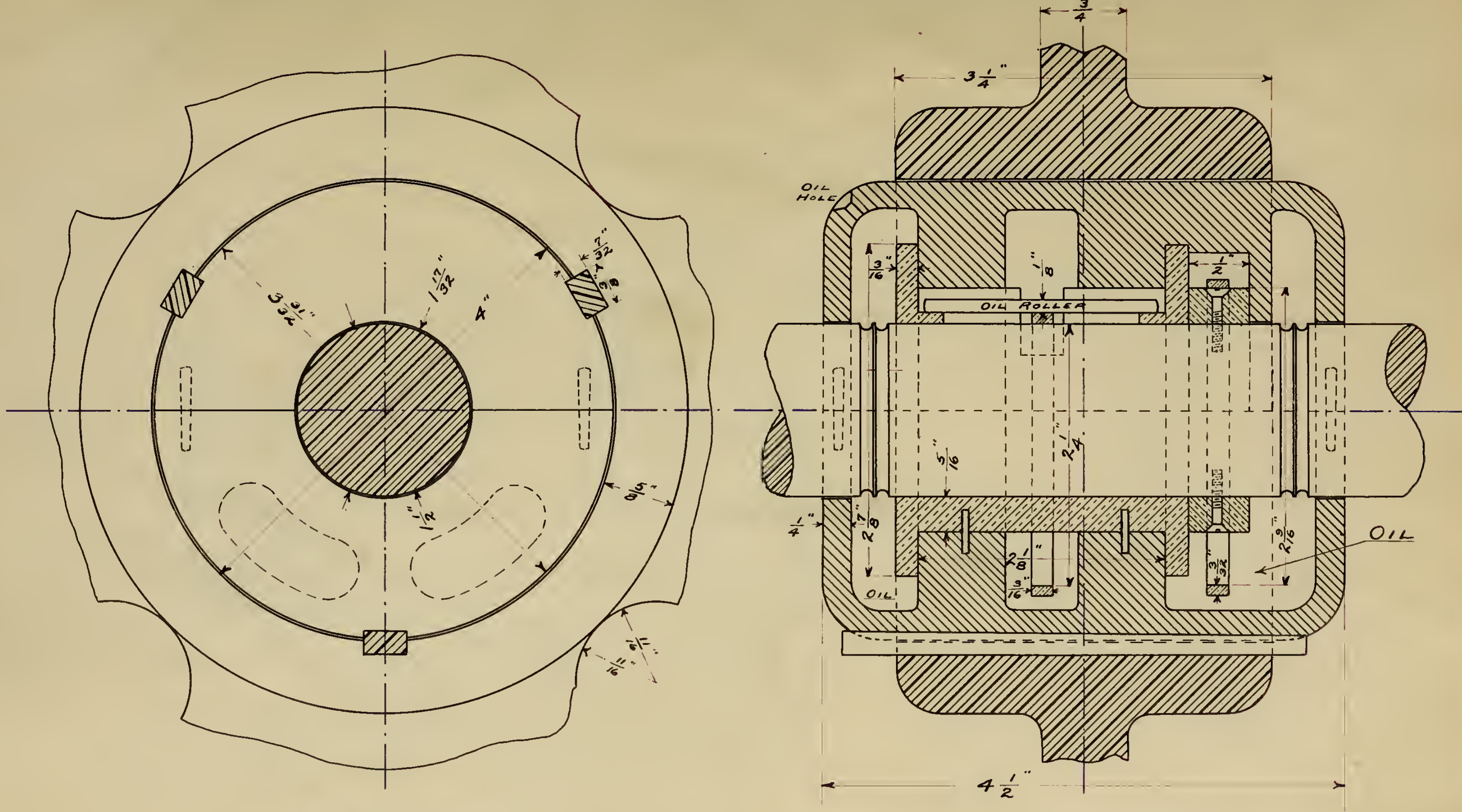
10 KW. HOMOPOLAR DYNAMO.

1000 AMP. - 10 VOLTS.

R.P.M. 2350.

SCALE : 1/8" = 1"

Farwell.



END VIEW

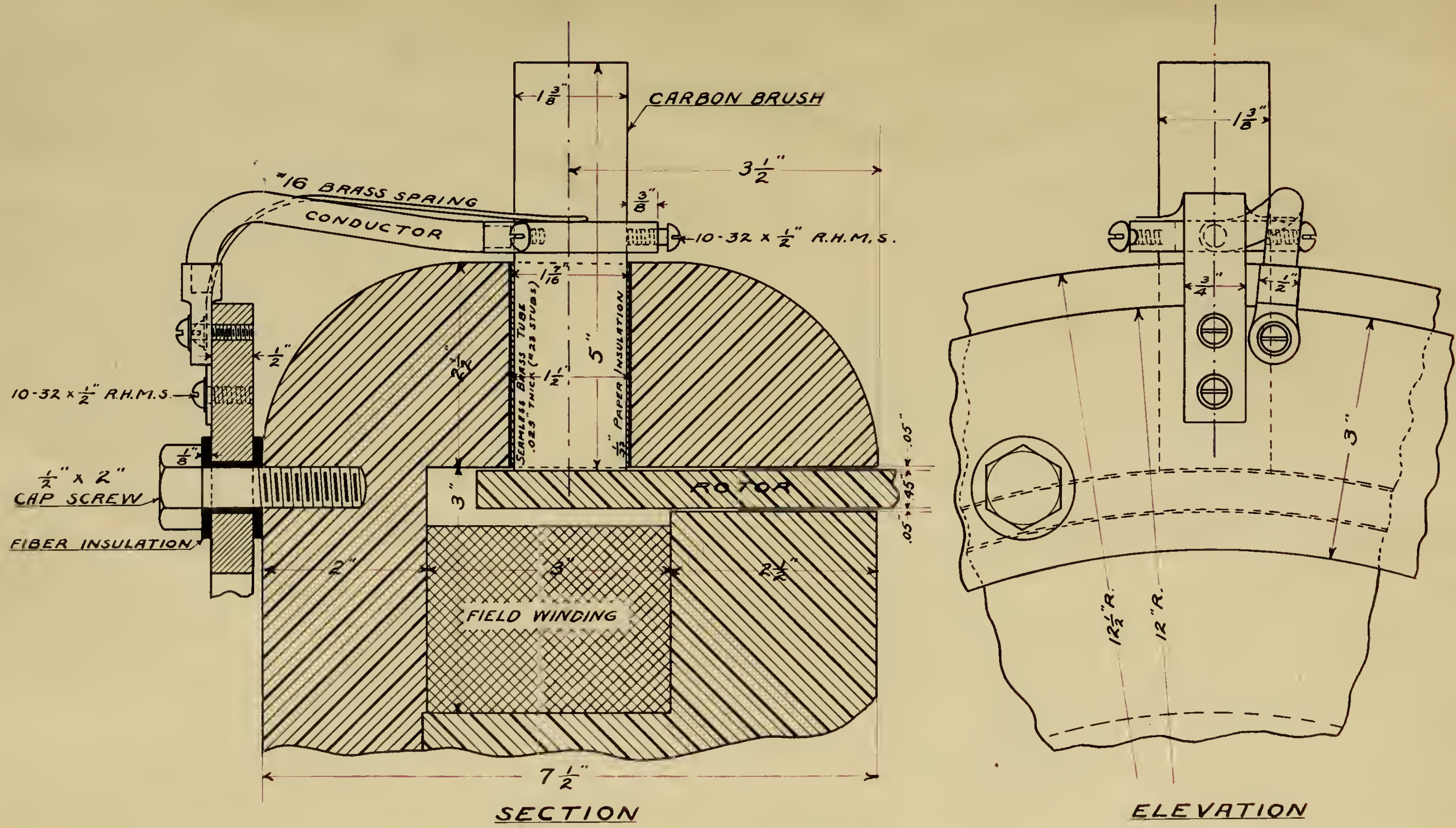
SECTION

BEARING FOR A 10 KW. HOMOPOLAR DYNAMO.

PROVISION FOR THRUST IN ONE BEARING ONLY.

SCALE : $\frac{3}{4}$" = 1"

Farwell.



Arrangement of Brushes on 10 KW. Homopolar Dynamo.

10 BRUSHES TO EACH FIELD RING : 100 AMPERES PER BRUSH.

SCALE : 1/2" = 1".

Farwell.